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INTRODUCTION

MCNP,[1] a Los Alamos National Laboratory Monte Carlo radiation transport code, is currently widely used in the medical community for a variety of purposes including treatment planning, diagnostics, beam design, tomographic studies, and radiation protection. This is particularly true in the Neutron Capture Therapy (NCT) community as evidenced by the numerous uses of MCNP in various publications.[2] The current widespread medical use of MCNP after its general public distribution in about 1980 attests to the code's general versatility and usefulness, particularly since its development to date has not been influenced by medical applications. This paper discusses enhancements to MCNP that could be implemented at Los Alamos for the benefit of the NCT community. These enhancements generally fall into two categories namely 1) those that have already been developed to some extent but are not yet publically available, and 2) those that seem both needed based on our current understanding of NCT goals, and achievable based on our working knowledge of the MCNP code.

MCNP is a general, coupled neutron/photon/electron Monte Carlo code developed and maintained by the Radiation Transport Group at Los Alamos. It has been used extensively for radiation shielding studies, reactor analysis, detector design, physics experiment interpretation, oil and gas well logging, radiation protection studies, accelerator design, etc. over the years. It is estimated to have about 300 person-years of development effort to its credit, and traces it roots back to the World War II Manhattan Project and scientists such as Fermi, von Neumann, Ulam and others.

MCNP is a three-dimensional (3-D) geometry, continuous energy physics code capable of modeling complex geometries, specifying material regions such as organs by the intersections of analytical surfaces. An example of the geometric complexity possible is shown in Fig. 1, where a partial MCNP model of the MIRD human phantom[3] is presented. This figure is a SABRINA code[4] 3-D picture of the MCNP model, where the flesh, ribs, and some organs have been omitted from the plot for clarity. This model will be discussed later in the context of potential medical imaging studies.

NEAR-TERM ENHANCEMENTS

There are a number of patches, techniques, etc. that have been developed in support of Los Alamos programs or for one-of-a-kind studies that have never been incorporated into MCNP because of lack of programmatic incentive. Most of this work exists in the form of patches which may or may not be consistent with the current version of MCNP, or as options in other codes. Examples of this category discussed below are the pinhole "camera" imaging capability, the lattice geometry capability, and the MCNP/SABRINA particle track display capability. While some of these capabilities already

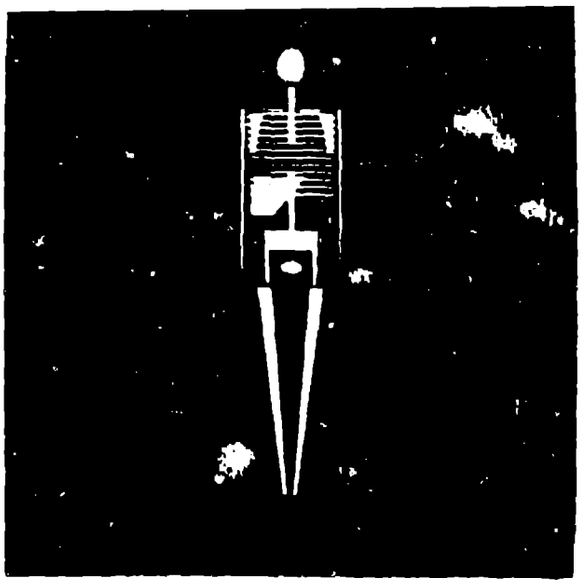

Figure 1. SABRINA-generated three-dimensional plot of the MCNP geometry model for the MIRD human phantom (some bones and organs not shown).

exist informally, getting them into the public code would require a non-trivial amount of work because they would have to be carefully integrated with all existing options in the code consistent with our high quality assurance standards.

The first example given in this category is the pinhole "camera" imaging capability that could in principle be used to generate the equivalent of medical images, such as those produced by Anger cameras, uniformly redundant arrays, or coded apertures. Such images could be used for the purpose of helping interpret radioisotope distributions and concentrations in regions of the body from actual medical images. This capability is illustrated using the MIRD human phantom model of Fig. 1. Photon-emitting radioisotopes were assumed to be present in the major bones (skull, spine, arms, pelvis, and legs) of the model, and were imaged through an ideal pinhole in an opaque medium as

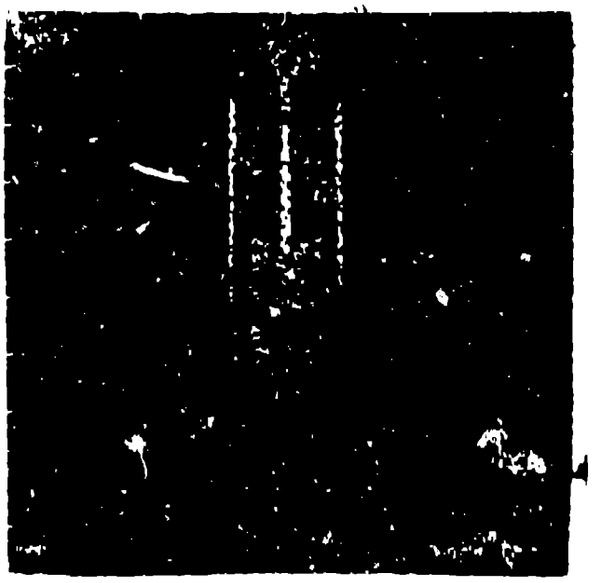

Figure 2. MCNP-computed image (simulating a nuclear-medicine image) of the MIRD phantom model with ^{99m}Tc in the major bones (arms, legs, pelvis, spine, and skull)

shown in Fig. 2. The bones with sources stand out clearly in the figure, and the effect of scattered radiation in flesh and other bones can be seen in the interstitial regions. Since scattered and unscattered radiation can be segregated quite easily in MCNP, this technique could be used to computationally quantify scattered components in actual measured medical images, subtract them out, and thereby produce more unambiguous images for medical diagnoses. This will be discussed further in a later section in connection with creating patient-specific MCNP models from CT and MRI images.

The second potential near-term capability discussed is the use of the lattice capability, developed for reactor studies, to model the many cells needed for accurate dose calculations in the head (or body). It is maintained by some radiation oncologists that more accuracy is needed in treatment planning to insure complete tumor kill, especially near material interfaces (e.g., brain/sinuses) where more approximate radiation transport calculations break down. This lattice geometry capability has been tested for a brain geometry with several million cells, but work is needed to provide for automatically varying the material composition of each cell. An example of the geometry created is shown in Fig. 3 where the 0.15 cm mesh is typical of MRI scan resolutions.

The third near-term potential category is that of using the SABRINA particle track display capability for qualitative scoping studies of neutron beam suitability for specific tumor treatment. The

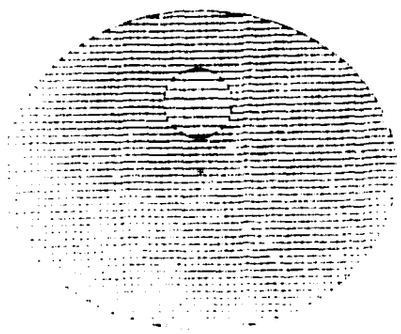

Figure 3. Plot of an MCNP geometry with the same voxel size as a typical MRI scan. The geometry description required only 23 lines of input using the MCNP lattice option, including the simulated tumor.

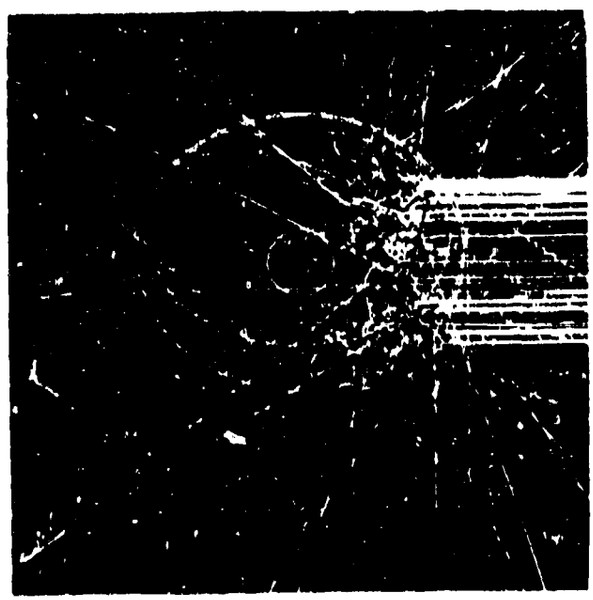

Figure 4. SABRINA-generated plot of neutron paths and scatterings inside the MCNP model of the MIRD phantom head.

MIRD phantom model head is shown in Fig. 4 with particle tracks shown. In this particular case, the energy of the incoming neutrons is too low, and most of them are thermalized before reaching the simulated tumor. Since this example was created with only 100 neutrons in the beam, such qualitative studies could be easily done in a quick scoping manner to determine the beam characteristics needed for a particular treatment scenario.

POSSIBLE FUTURE ENHANCEMENTS

With regard to longer range enhancements, it is felt that a number of new MCNP features could be developed that would be useful to the NCT community in the future. This assertion is based on the fact that the code was not developed with medical use in mind, and that improvements in efficiency, physics and ease of use for this purpose are reasonably attainable at Los Alamos based on our working knowledge of MCNP. The most attractive of these seems to be the potential for performing patient-specific MCNP computations for diagnostic test interpretation and treatment scenarios, and for improving computational efficiency in order to perform near-real time treatment planning with these models.

By 1) generating patient-specific body geometry from CAT and/or MRI scans and 2) simulating diagnostic images (e.g., CAT, Anger camera, SPECT) using these patient models, 3) high-accuracy dose distributions, radioisotope concentration assay, and scatter corrections would be possible for these patients. Such patient-specific calculations would undoubtedly improve the quality of care for patients, as well as lead to a more quantitative understanding of the effects of dose on tumors and healthy tissue function.

Ultimately, in order for MCNP to be used for routine clinical treatment planning, it will be necessary speed up the calculations by several orders of magnitude. This can be accomplished by several means. First, the regular rectangular mesh that results from creating patient-specific geometries from CT and MRI scans would be much simpler to calculate than the general geometry that is now built into MCNP. It has already been demonstrated at Los Alamos that providing special coding for regular mesh decreased computational time by a factor of 10 for similar problems. Secondly, computation time is becoming increasingly affordable, in particular with regard to desktop workstations. A Sun Sparc 2 now runs MCNP at about 1/4 the speed of one Cray YMP processor. The Sparc 10 that should be available in 1993 will be equivalent to about 4 Cray processors, a factor of 16 increase in computing power. Further advances are inevitable. Finally, Los Alamos and others are working on the "multi-tasking" of MCNP on workstations on a given network in order to fully utilize available CPU's when the workstation owner is not doing so. At Los Alamos there is a cluster of 13 IBM RISC 6000's, which, when multi-tasked with MCNP, will equal about 10 Cray processors.

SUMMARY AND CONCLUSIONS

In conclusion, it appears that patient-specific 3-D treatment planning and diagnosis is possible if a number of relatively straightforward improvements in MCNP can be implemented. Use of this capability for near real-time therapy planning should be practical in the near future when factoring in the likely advances in workstation computing power and networking. With a coordinated effort from the NCT community, it should be possible to obtain support from DOE Defense Programs dual-use technology transfer initiatives for Los Alamos to provide the described MCNP enhancements described for the NCT community.

REFERENCES

1. Briesmeister, J. F., ed. (1986), *MCNP - A General Monte Carlo Code for Neutron and Photon Transport - Version 3A*, (Los Alamos National Laboratory report LA 7396 M).
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4. West, J. T., III (1986), "*SABRINA, An Interactive Three-Dimensional Geometry-Modeling Program for MCNP*," (Los Alamos National Laboratory report LA 10988 M).

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